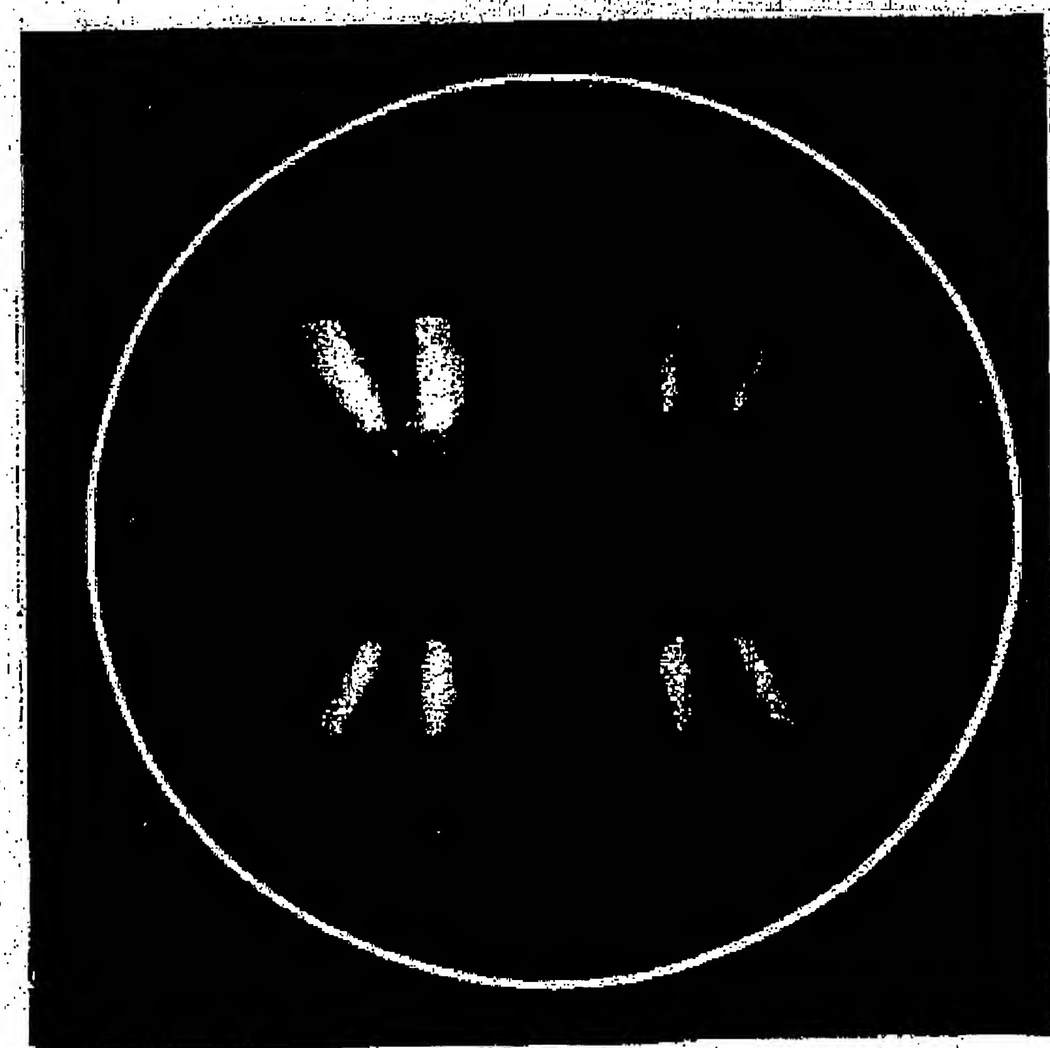
mikroelektronik

High-rate Sputtering System for Two-sided Coating HZS-04



High-rate Sputtering

The high-rate sputtering system based on plasmatron sputtering sources has been developed within the last twelve years to the dominant vacuum film deposition process in the microelectronics, hybrid microelectronics, and electronics fields. In these industrial branches the process step of coatings has become of special significance, since the properties and quality of the sputtered films to a large extent determine the function and results of microelectronics and electronic components. The increasing demands on microelectronics and electronic components with respect to their parameters such as structure width, edge covering, low concentration of mobile charge carriers, material choice, stochiometry, current carrying capacity, and contact properties stimulate the use of high-rate sputtering systems, particularly in microelectronics and electronics.

Beyond this, applications of high rate sputtering reach from the production of reflection reducing, heat ray reflecting, and mirror films in the optical and glass industries, from the production of wear-resistant coatings in the tool industry, from the production of decorative films and foils, plastic and metallic parts to the production of functional films for display elements including modem matrix displays, storage for modem computer technology, audio- and video discs, solar cells and solar absorbers. An overview of applications of high rate sputtering is given in Table 1.

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INDUSTRY BRANCH	FILM FUNCTION	FILM MATERIAL	EXAMPLE OF RESULTS
ELECTRONICS	adhesion layer resistor conductor and contact protective film reflection film magnetic memories dispers. hardened film	NiCr CrNi, Ta_2N, TaAl, Pt, CrSIAl Cu, FeNi, CuNi, Al SiO_2, Ta_2O_5, AL_2O_3, Al, Cr Cu, Cr, CaCr CuTiFe	capacitors, chip resistor posistor, varistor, resonator thin film thermometer strip conductor audio and video discs memory discs, tapes thermopressure head
MICROELECTRONICS	conductors, contacts Schottky contacts simultaneous contacts backside metallization transparent contacts resistors	Al, AlSi, ALSICu Pt, Mo, WTi CrNI, Cu Al-Ni-Au, Al-Ni $InSO_x$ CrSi, CrSIW, Cr	unipolar and bipolar IC power switching circuits transistors silicon rectifiers display components resistor networks
HYBRID-MICROELECTRONICS	resistors conductors and contacts sealing films dielectric films	NiCr, CrSi AL, FeNi Cr_2O_3, Al_2O_3 SiO_2, TiO_2, Ta_2O_5	hybrid switching circuits solder and bond capable contacts, D/A converters sensors
SOLAR INDUSTRY	absorption, function films	TiO_2-Ag-TiO_2, Cd_2SnO_4	solar absorbers, solar cells
GLASS INDUSTRY	reflection selective infrared reflection	Al, AL-Ti, CuSn TiO_2,-Cu- TiO_2	mirrors architectural glass, heat-ray reflecting films
OPTICAL INDUSTRY	reflection reduction	SiO_2, TiO_2	optical glasses
TOOL INDUSTRY	wear protection friction reduction	WC, TiN, Al_2O_3, TaC Ag, Mo_2S, C	tools, boring bits bearings
TRANSPORT. INDUSTRY	heat reflection	TiN	automobile sun roofs
PACKAGING INDUSTRY	decoration	Al, Cr, Cr-Alloy, Cu-Leg., TiN	plastic and metal parts

Table 1. Applications of high rate sputtering

Requirements for High-rate Sputtering Systems

The highest requirements for quality are placed on vacuum coating processes by microelectronics and electronics.

Films of pure metals, high melting point metals, metal alloys, partially oxidized films, and oxide films, silicide films as well as, to an increasing degree, multilayer films, are deposited onto the most varied substrates.

In addition to integrated circuits having increasing levels of integration, thus smaller structural widths, and other semiconductor components, coating is also to be carried out in power rectifiers, resulting in higher efficiency and lower costs.

Vacuum coating must take place in low contamination conditions, i.e., under stringent requirements on the residual gas conditions in the coating chamber. Multilayer coating tasks require great flexibility with respect to the process parameters with simultaneous high reproducibility, the introduction of additional process steps, e.g., pre-treatment processing, and a high level of automation of the system.

For the use of high vacuum coating systems in electronics and other industrial branches, requirements regarding productivity of the system and low cost of each coated film surface take certain key parameters of the film as a priority.

The substrates to be coated for different components differ markedly in form and dimensions. Structured films with limited requirements on the structural accuracy must in part be isolated in the vacuum process in order to avoid costly subsequent structuring processes. Frequently, the coating of the film system with adhesion layers or special alloys is required, in order to achieve adequate adhesion to specific substrates. The coating of temperature sensitive substrates demands suitable process techniques.

High-rate Sputtering System HZS-04

The multiplicity of requirements on high rate sputtering systems cannot be completely fulfilled economically by one system for the various application areas. The equipment of high-rate sputtering systems is therefore characterized by a modular construction that allows the realization of suitable system technical solutions for different application areas.

In this way the known systems HZS-02 and HZS-03 came into existence. As a new development with the Manfred von Ardenne research institute the high-rate sputtering system HZS-04 comprises high productivity passthrough sputtering systems. Principal characteristics of the system HZS-04 are the dual plasmatron arrangements and the arrangement of up to four plasmatron sources in the main coating chamber. The dual arrangement of the plasmatron sputtering chamber makes possible two-sided coating with higher productivity due to the shortest transport path of the substrate carrier (pallets). The arrangement of two plasmatron sources makes possible the deposition of two-film systems. By dual arrangement of the plasmatron sputtering sources is understood the arrangement of sources in the chamber in opposite positions in the coating chamber with target surfaces turned toward each other.

Application Possibilities and Modifications

The inline sputtering systems HZS-04 are of prime suitability for:

- high-productivity two-sided coating
    - two-sided coating of components
    - one-sided coating of substrates arranged opposite each other (doubling of productivity)
- sputter-deposition of two film systems
    - two-sided coating
    - one-sided coating

The characteristic system configuration for these application cases is the high-rate sputtering system HZSK-04 with a total of 4 plasmatron sources in the coating chamber.

Further application possibilities on the basis of the HZSK-04 system result from

- reduction of the configuration, e.g.,
    - two-sided coating with one film
    - one-sided coating with two films
    - one-sided coating with one film.
      With the mentioned application possibilities of the one-sided coating the coating can optionally take place from above (simple substrate holder) or from below (increased cleanliness) with one or two films. The reduction of the configuration consists merely in the lowering of the number of plasmatron sources installed or used in the system.
- expansion of the configuration through additional structural groups and modifications.

High-rate Sputtering System for Capacitors HZSK-04

Application Goal

System HZSK-04 is a high-production vacuum coating system for the two sided coating with two film systems through high-rate sputtering with the plasmatron. The dual arrangement of in total 2 by 2 plasmatron sputtering sources allows the substrate to be coated on both sides with a two-layer film in one pass through the vacuum system.

In the configuration mentioned, a principal area of use of the HZSK-04 is the metallization of capacitor ceramic with a noble-metal-free two layer system. Through reduction or expansion of the configuration these systems are to be used also for the above mentioned coating tasks.

Examples for this are in the Manfred von Ardenne research institute, realized through production use of HZS-04 system, for the sputtering processes with additional process requirements such as reactive coating of indium-tin-oxide (ITO) for the production of LCD display elements, the reactive coating of titanium nitride on glass and the partially reactive deposition of thin film chip resistors with high requirements on the film thickness uniformity, parameter reproducibility and productivity.

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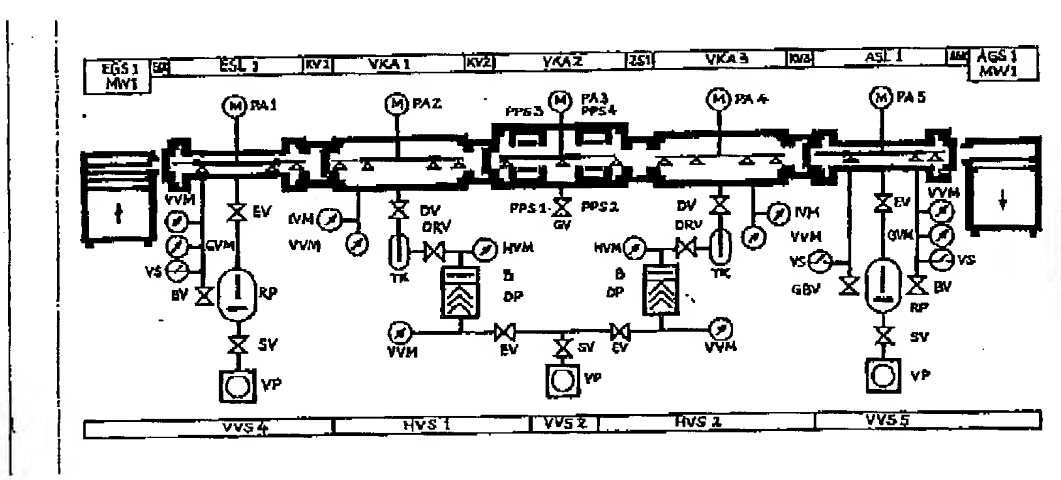
Design

The design of system HZSK-04 vacuum system, pallet transport system and measurement stations is represented schematically in Figure 1

Figure 1 HZSK-04 Schematic

Figure 1 Abbreviations:

EGS 1 input station
PA 1...5 pallet drive 1...5
RP Roots blower pump
GVM rough vacuum gauge
MW 1 magazine carriage for 10 pallet frames
PPS 1;3 plasmatron sputtering source for first film
VVM backing vacuum measuring gauge (Pirani)
VP slide vane rotary vacuum pump
ESL 1 Input gate
PPS 2:4...3 plasmatron sputtering source for second film
DP oil diffusion pump
HVM high vacuum measuring guage (Penning)
KV 1...3 gate valve 1...3
B oil vapor barrier
VKA 1 vacuum chamber 1
VKA 2 vacuum chamber 2
BV vent valve
GBV protective gas inlet valve
SV safety valve
HVS 1;2 high vacuum pump system 1;2
VS vacuum switch
VVS:2;4;5 backing vacuum pump system 2;4;5
VKA 3 vacuum chamber 3
ASL 1 output gate
AGS 1 output station 1
EV corner valve
DV passthrough valve
DRV suction power throttle
GV gas inlet valve
IVM ionization vacuum gauge
ZS 1 intermediate piece
TK cold trap



Input Gate ESL 1

- Flat receiver of stainless steel with minimum volume
- Short evacuation and vent times
- Electromagnetic vent valve with dust filter
- Pneumatically actuated input flap
- temperature of top and bottom controlled through warm water circuit
- Chamber top tiltable upwards, chamber bottom lowerable
- Attachment flange NW 63 for backing pump system VVS 4

Backing Pump System VVS 4, 5

- Rotary vacuum pump with suction capability of 60 m^3h^{-1}
- Safety valve
- Roots blower vacuum pump with 600 m^3h^{-1}
- Noise protection hood
- Stainless steel pump tubing NW 63
- Connection to system through electromagnetic comer valve

Gate Valves KV 1, KV 2, KV 3

- Pneumatically actuated high vacuum valves
- Rectangular valve opening 600 x 100 mm^2

Vacuum Chamber VKA 1 (Illustration 2)

- Flat receiver of stainless steel with small inner surface for assurance of stable low residual gas levels
- Water-cooled chamber top and bottom
- Chamber top tiltable upwards, bottom lowerable with a device
- Flange NW 250 for attachment of the high vacuum pump system HVS 1

High Vacuum Pump System HVS 1 and HVS 2

- Identical design of the high vacuum pump systems HVS 1 and HVS 2
- Oil diffusion pump with suction power of 3 000 l/s^{-1} *[sic]*
- Water-cooled oil vapor trap for reducing the diffusion of propellant vapors into the vacuum chambers
- High vacuum measuring gauge
- Liquid nitrogen cold trap for reduction of the residual gas pressure in the vacuum chambers
- Suction-power throttle for setting the operating pressure required for sputtering (suction power of the cold trap is not throttled)
- Connection to the vacuum chamber through pneumatically activated passthrough valve NW 250
- Common connection of the high vacuum pump systems HVS 1 and HVS 2 to the backing vacuum pump system VVS 2

Backing Vacuum Pump System VVS 2

- Slide vane rotary vacuum pump with suction power of 150 m^3/h^{-1}
- Safety valve
- Noise protection hood
- Stainless steel pump line NW 63
- Connection to the high vacuum pump systems via hand-operated corner valve (service)

Vacuum Chamber VKA 2 Illustration 3

- Coating chamber with small inner surface without connection flange for high vacuum pump systems
- Dual arrangement of two plasmatron sputtering sources PPS-25R in each case, on the chamber top and chamber bottom, makes possible:
  - High utilization factor of the sputtered target material
  - Short cycle times
  - High productivity
- Simple target replacement in the service space through assembly of the chamber top and bottom with the plasmatron sputtering sources on plasmatron carriages
- Chamber top in lift carriage that can pivot 180° for target replacement (Illustration 4)
- Automatic disconnection of the electric supply of the plasmatron sputtering sources upon lifting of the chamber top or lowering of the chamber bottom
- Four water loops for the cooling of target, plasma screens, chamber top, and chamber bottom
- Piezoceramic gas inlet valve for operating gas at the chamber back wall
- Easily replaceable screening plates for the protection of the coating chamber and of the pallet transport system against scattered vapor

Vacuum Chamber VKA 3

- Designed and technically equipped as vacuum chamber VKA 1
- Flange NW 250 for connection of the high vacuum pump system HVS 2

Pressure Control System DRS

- BA gauge tube on vacuum chamber VKA 1
- HP gauge tube on vacuum chamber VKA 3
- Piezoceramic gas inlet valve on vacuum chamber VKA 2
- Ionization vacuum gauge with automatic measurement-range switching and digital display
- Electronic controller that sets the gas inlet valve in dependence on the actual value and the selected target value of the operating gas pressure
- Measurement of the initial pressure with HP and BA gauge tubes

Output Gate ASL 1

- Designed and technically equipped as input gate ESL 1
- Additional gas inlet valve enables flooding with inert gas for accelerated cooling of the substrate
- Connection flange MW 63 for the backing vacuum pump system VVS 5

Pallet Exchange System

- Input station EGS 1
- Output station AGS 1
- 3 magazine carriages for receiving 10 pallet frames in each case
- Automatic input of the pallet frames from magazine carriages of the input station into the input gate
- Automatic output of the pallet frames from the output gate into magazine carriages of the output station
- Uninterrupted system operation through a third magazine carriage that is alternately loaded and unloaded

Pallet Transport System

- Motor driven pallet drives PA 1 and PA 5 of the gates and PA 2, PA 3, and PA 4 of the vacuum chambers
- Sensors for position determination of the pallet frames in the system
- Linear transport of the pallet frames in forward and backward motion
- Coating possible in single pass or multiple pass
- Transport speed 100 mm s^{-1}
- Propulsion of the pallet frames by means of stainless steel frictional wheels that are rigidly coupled outside the vacuum chamber
- Reduction of the leakage rate of all rotary feedthroughs by means of design with two shaft sealing rings, between which a backing vacuum is pumped

Plasmatron Sputtering Source PPS-25 R (Illustration 5)

- Maximum power 25 kW,
  maximum usable power dependent on target material and target thickness
- Target dimensions 610 x 160 x 16 mm^3 (Standard), smaller target thickness possible
- Indirect target cooling through copper heat sink for low power densities
- Direct target cooling for higher power densities
- Water-cooled plasma screen at ground potential acts as anode for the gas discharge
- Increase of the film-thickness uniformity through appropriate design of the upper portion of the plasma screen as aperture diaphragm (Illustration 6)

Process

The explanation of a process for two-sided coating with a two-film system on the HZSK-04 system takes place using the example of the metallization of capacitor ceramic with the noble-metal-free film system NiCr-Cu.

- Input of the pallet frame with loaded pallet insert from the magazine carriage via the input station EGS 1 into the input gate ESL 1
- Closing of the input shutter EGK and evacuation by means of the backing vacuum pump system VVS 4
- Transport of the pallet frame into the vacuum chamber VKA 1
  (After the venting the input gate stands by for the input of the next pallet frame.)
- Evacuation of vacuum chamber VKA 1 through the high vacuum pump system HVS 1
- Opening of the gate valve KV 2
- Throttling of the high vacuum pump systems HVS 1 and 2 through the suction power throttles DRV
- Setting of the operating gas pressure in the vacuum chambers VKA 1...3 through the pressure system
- Switching on of the dual-arranged plasmatron sputtering sources PPS 1 and PPS 3 for the deposition of the first film
- Pallet transport in single- and multiple-pass for two-sided deposition of the first film (NiCr)
- Switching off of the plasmatron sputtering sources and the pallet transport
- Closing of the gate valve KV 2
  (The vacuum chamber VKA 1, after a high vacuum cycle, stands by to accept the next pallet frame.)
- Switching on of the plasmatron sputtering sources PPS 2 and PPS 4 for the deposition of the second film
- Pallet transport in multiple-pass for two-sided deposition of the second film (Cu or CuNi
- Switching off of the plasmatron sputtering sources and the pallet transport
- Closing of the gas inlet valve
- Transport of the pallet frame into the output gate ASL 1 (The vacuum chambers VKA 2 and VKA 3, after a high vacuum cycle, are ready for the coating of the next pallet.)
- Flooding of the output gate ASL 1 with nitrogen at an intermediate pressure for accelerated cooling of the substrate
- Ventilation of the output gate ASL 1
- Output of the pallet frame into the magazine carriage of the output station AGS
- Closing of the output shutter AGK and evacuation by means of the backing vacuum pump system VVS 5
- Standby of the output gate ASL 1 for acceptance of the next pallet frame

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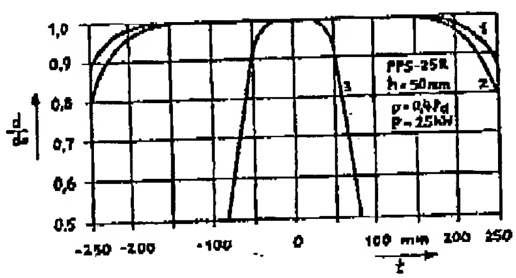
Illustration 6

Film thickness distribution

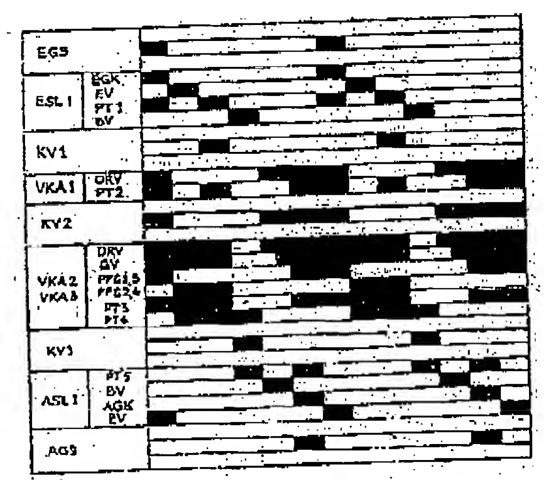
PPS-25 R



1 with ⎤ Aperture correction, moved
2 without ⎦
3 stationary, transverse to movement direction

Illustration 7

Example of a cycle scheme for the most important elements



The described process takes place, as is evident from the cycle scheme (Illustration 7), in a time-shared manner for several pallet frames. The system-conditioned cycle time results from the greatest sum of partial times of the individual function elements within a system section that are required for the passage of a pallet frame up to the reestablishment of the starting state. In many cases, it is possible within the system-conditioned cycle time to develop simple coating technologies for high productivities.

In the case of increased demands on the coating parameters, the cycle time is determined by individual process steps that take into account special technological requirements. This cycle time exceeds the system-conditioned cycle time and is referred to as a technologically conditioned cycle time.

Control and Operation

The control of the system takes place through a system computer K 1520, to which an office computer A 5120 is connected as the operating terminal (Illustration 8).

The decisive process variables, such as power of the individual plasmatron sputtering sources, initial pressure in the high vacuum chambers, and pressure of the operating gas in the coating chamber, are prescribed and monitored by the system computer.

Resulting from the use of the office computer A 5120 for system operation is a series of advantages for the user:

- high process flexibility through mini-film memory for user programs
- different user programs can be called up through simple operating steps
- direct input possibility for the most important coating parameters
- dialog-oriented operation of the system via the keyboard and display screen of the operating terminal (office computer A 5120)
- Possibility of software-supported operation of one or several system control elements
- Problem-oriented system operation for production operation, process development, or service.

In the "manual control" operating mode, the possibility exists of direct access to the hardware of the most important system control elements. A keyboard provided for this is located alongside the graphical representation SB 1 (Illustration 9) that signalizes the most important system conditions.

Graphical representation SB 2 (Illustration 10) on the top of the vacuum chamber VKA 3 contains indicators and operating elements of the pressure system as well as the indicators of voltage, current, and power of the plasmatron sputtering sources.

Two plasmatron power supplies PSV 25 (cabinets 4 and 5) for a maximum power of 25 kW are assigned to the plasmatron sputtering sources in the top and bottom of the coating chamber (Illustration 11).

Characteristics of the plasmatron power supply PSV 25:

- Power regulation
- Switchable voltage ranges
- Short-circuit proof
- Electronic arc suppression
- Connection possibility for maximum of three plasmatron sputtering sources
- Automatic sputtering turn-on
- Energy meter
- Interface for external control through system computer
- Digital pre-specifying of the target value for power of the plasmatron sputtering sources
- Manual control panel for all functions of the power supply
- Digital display of voltage, current, power of the plasmatron power supply; voltage and current of the auxiliary power supply
- Radio interference suppression

Control cabinet 1 contains vacuum meters and switching units arranged in an easily surveyed manner, as well as the system computer and the system control (Illustration 12).

Installed in switch cabinet 3 under vacuum chamber VKA 3 are the power supply for the liquid-nitrogen refilling equipment, power switching units, and the control of the pallet exchange system.

The compactly structured and easily accessed pneumatic control module contains the pressurized-air processing unit and electro-pneumatic control units.

The service-compatible cooling system with connections for cold and warm water comprises two thermostats U 160 for temperature control of the input and output gates, manual shut-off valves arranged on a frame, throughput gauges for sight control and for manual adjustment of minimal throughput in the individual cool-water loops, as well as water-flow monitors.

Technical Data

Required floor space 9.0 x 6.2 m^2
(Total system, backing vacuum pump systems, control cabinets)

Dimensions
System with pallet exchange system

Length	8000 mm
Depth	5200 mm
Height	2200 mm

Power supply and control cabinets
Cabinet 1, 4, 5 (W x D x H) 800 x 800 x 2170 mm^3

Backing vacuum pump systems with noise-protection hood
VVS 2, VVS 4, 5 (W x D x H)
each 1020 x 1435 x 1100 mm^3

Cooling system (W x D x H) 1800 x 400 x 875 mm^3

Total Weight 6100 kg

Minimum floor load rating

Vacuum chambers	1000 kp m^{-2}
Control cabinets	750 kp m^{-2}

Media

- Cool water

Pressure	
Initial Temperature	15 (+10, -5) °C
Requirement	3.0 m^3 h^{-1}
Connection	1½ "

- Warm water

Pressure	0.15 MPa...0.5 MPa
Temperature	(40...60) °C
Connection	¾ "

- Electric power supply
3N SL 50 Hz 380/220 V ± 5%

Connected load	max. 160 A
Power draw	max. 90 kVA unsym.

- Operating gases

Argon	pressure	max. 10 kPa
	requirement	10 l h^{-1}
	connection	NW 4

Liquid nitrogen	requirement	6 l h^{-1}
Pressurized air	pressure	(0.6 ± 0.05) MPa
	connection	½"
Gas-form nitrogen	requirement	2 m^3 h^{-1}
	connection	NW 7

Climate Requirements
Application class according to TGL 9200, sheet 3:
+15/+35/+35/80/1101
TGL 9200/03
Protection grade IP20

Productivity
The productivity is dependent on process.
Availability of the system $V_D \geq 85\%$

Examples:

1. Ceramic discs Ø 8mm
Two-film system
Cycle time 4 minutes
Productivity 2682 pieces per pallet

2. Ceramic surface film capacitors 30 x 30 mm^2
Two-film system
Cycle time 4.75 minutes
Productivity 196 pieces per pallet

Pallet Transport Speed 100 mm s^{-1}

Final Pressure of the Vacuum Chambers VKA 1...3
(cooling with liquid nitrogen) $p \leq 4 \cdot 10^{-4}$ Pa

Plasmatron Sputtering Sources PPS-25R

Maximum power	25 kW
Target material 1st film	NiCr 80/20
2nd film	E-Cu; CuNi
Film thickness uniformity on 480 x 480 mm^2 pallet	≤ ± 15%

Plasmatron Power Supply PSV 25

Power	25 kW
Cathode voltages	0...-470/-520/-635/
Cathode current	0...60 A

Subject to changes in the interest of technical improvement.

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Illustration Captions